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Probing the standard model with hadronic WZ production*

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ABSTRACT

The cross section for producing WZ pairs at hadron colliders is calculated to order α_s for general C and P conserving WWZ couplings. The effects of the next-to-leading-order corrections on the derived sensitivity limits for anomalous WWZ couplings are discussed. The prospects for observing the approximate amplitude zero, which is present in the standard model WZ helicity amplitudes, are also discussed.

1. Introduction

The production of WZ pairs at hadron colliders provides an excellent opportunity to study the WWZ vertex[1,2,3]. In addition, the reaction $p\overset{(-)}{p} \to W^\pm Z$ is of interest due to the presence of an approximate zero in the amplitude of the parton level subprocess $q_1\bar{q}_2 \to W^\pm Z$[3] in the standard model, which is similar in nature to the well-known radiation zero in the reaction $p\overset{(-)}{p} \to W^\pm\gamma$[4]. Previous studies on probing the WWZ vertex via hadronic WZ production have been based on leading-order calculations[2]. This report summarizes the results of a comprehensive study[5] of hadronic WZ production based on an $\mathcal{O}(\alpha_s)$ calculation of the reaction $p\overset{(-)}{p} \to W^\pm Z + X \to \ell_1^\pm \nu_1 \ell_2^+ \ell_2^- + X$ for general, C and P conserving, WWZ couplings.

2. Anomalous Couplings

In the standard model (SM), the WWZ vertex is uniquely determined by the $\mathrm{SU}(2)\otimes\mathrm{U}(1)$ gauge structure of the electroweak sector, thus a measurement of the WWZ vertex provides a stringent test of the SM. The most general WWZ vertex, which is Lorentz, C, and P invariant, contains three free parameters, g_1, κ, and λ, and is described by the effective Lagrangian[6]

$$\mathcal{L}_{WWZ} = -i\, e \cot\theta_{\mathrm{W}} \Big[g_1 (W^\dagger_{\mu\nu} W^\mu Z^\nu - W^\dagger_\mu Z_\nu W^{\mu\nu}) + \kappa W^\dagger_\mu W_\nu Z^{\mu\nu} + \frac{\lambda}{M_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu Z^{\nu\lambda} \Big].$$

At tree level in the SM, $g_1 = 1$, $\kappa = 1$, and $\lambda = 0$.

The Z boson transverse momentum spectrum is very sensitive to anomalous WWZ couplings. At the Tevatron, the $\mathcal{O}(\alpha_s)$ QCD corrections are modest and sen-

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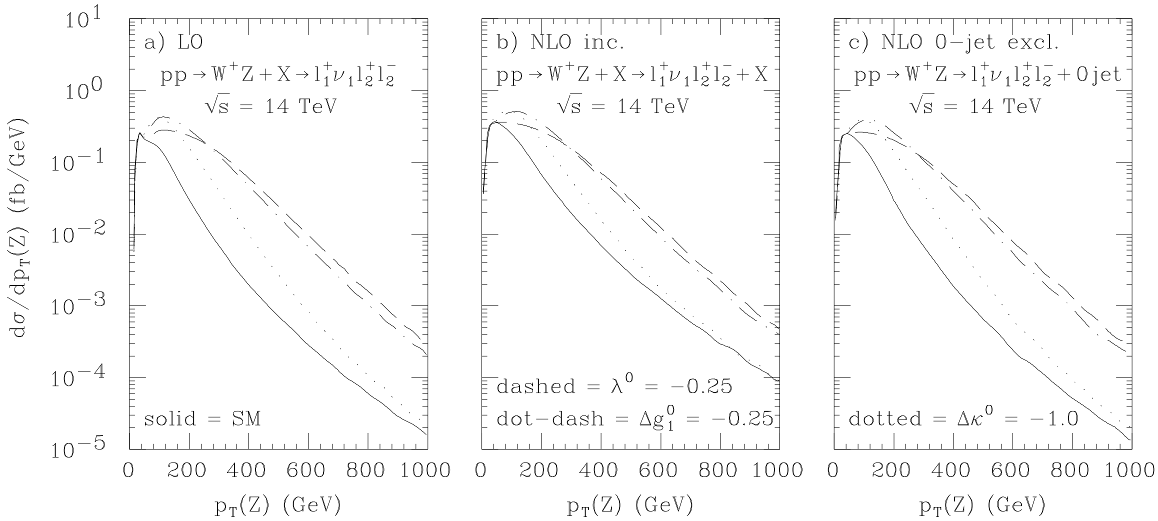

Fig. 1. Transverse momentum distribution of the Z boson for the standard model and three values of anomalous couplings. Parts a), b), and c) are the results for the LO, NLO inclusive, and the NLO 0-jet exclusive cross sections, respectively.

sitivities are only slightly affected by the QCD corrections. At the LHC, on the other hand, the inclusive $\mathcal{O}(\alpha_s)$ QCD corrections in the SM are very large at high $p_T(Z)$, and have a non-negligible influence on the sensitivity bounds which can be achieved for anomalous WWZ couplings; compare Figs. 1a and 1b. The large QCD corrections are caused by the combined effects of destructive interference in the Born subprocess, a log-squared enhancement factor in the $q_1 g \to WZq_2$ partonic cross section at high transverse momentum[7], and the large quark-gluon luminosity at supercollider energies. The size of the QCD corrections at high $p_T(Z)$ can be significantly reduced, and a significant fraction of the sensitivity lost at the LHC energy can be regained, if a jet veto is imposed, *i.e.*, if the $WZ+0$ jet exclusive channel is considered; see Fig. 1c.

3. Approximate Amplitude Zero

Recently, it has been shown that the SM amplitude for $q_1\bar{q}_2 \to W^\pm Z$ at the Born level exhibits an approximate zero at high energies, $\hat{s} \gg M_Z^2$, located at[3]

$$\cos\Theta^* \approx \pm\frac{1}{3}\tan^2\theta_{\rm W} \approx \pm 0.1,$$

where Θ^* is the scattering angle of the Z boson relative to the quark direction in the WZ center of mass frame. The approximate zero is the combined result of an exact zero in the dominant helicity amplitudes $\mathcal{M}(\pm,\mp)$ and strong gauge cancellations in the remaining amplitudes.

The approximate amplitude zero in WZ production causes a slight dip in the rapidity difference distribution, $\Delta y(Z,\ell_1) = y(Z) - y(\ell_1)$, where ℓ_1 is the charged

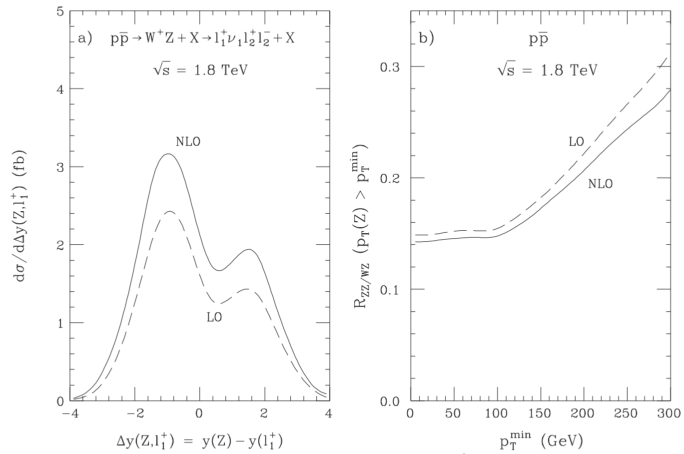

Fig. 2. a) Distribution of the rapidity difference $y(Z) - y(\ell_1^+)$. b) The ZZ to WZ cross section ratio as a function of the minimum transverse momentum of the Z boson.

lepton from the decaying W boson; see Fig. 2a. At the Tevatron energy, order α_s QCD corrections have a negligible influence the shape of the $\Delta y(Z, \ell_1)$ distribution. At the LHC, however, $\mathcal{O}(\alpha_s)$ QCD effects completely obscure the dip, unless a jet veto is imposed.

Cross section ratios can also be used to search for experimental consequences of the approximate amplitude zero. The ratio of ZZ to WZ cross sections as a function of the minimum Z boson transverse momentum, $p_T^{\rm min}$, increases with $p_T^{\rm min}$ for values larger than 100 GeV; see Fig. 2b. This increase in the cross section ratio is a direct consequence of the approximate zero. QCD corrections have a significant impact on the ZZ to WZ cross section ratio at the LHC unless a jet veto is imposed.

The $\Delta y(Z, \ell_1)$ distribution and the ZZ to $W^\pm Z$ cross section ratio are useful tools in searching for the approximate amplitude zero in WZ production. However, for the integrated luminosities envisioned, it will not be easy to conclusively establish the approximate amplitude zero in WZ production at the Tevatron or the LHC.

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